Flocculation, Optics and Turbulence in the Community Sediment Transport Model System: Application of Oasis Results

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LONG-TERM GOALS

The goal of this research is to develop greater understanding of how the flocculation of fine-grained sediment responds to turbulent stresses and how this packaging of sediment affects optical and acoustical properties in the water column.

OBJECTIVES

1. Quantify the effects of aggregation dynamics on the size distribution of particles in the bottom boundary layer;
2. Quantify how changes in particle packaging affect the optical and acoustical properties of the water column.
3. Develop models describing the associations between particle aggregation, stress, and the acoustical and optical fields.

APPROACH

The approach is to obtain measurements that permit comparisons of temporal evolution of bottom stress, suspended particle size, and optical and acoustical properties in the bottom boundary layer. The instrumentation is mounted on bottom tripods. Our **M**odified **IN** Situ **S**ize and **Se**ttling **C**olumn **T**ripod (MINSSECT) has been deployed multiple times in four different field years to measure optical beam attenuation, suspended particulate mass and particle size distributions. The MINSSECT is

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instrumented with a Sequoia Scientific LISST-100x Type B laser particle sizer and a Digital Floc Camera (DFC) to measure a range of particle diameters from approximately 2 μm to 4 cm. The LISST also measures the beam attenuation coefficient, c_p. Size-versus-settling-velocity measurements are made with a digital video camera that images a slab of fluid in a settling column. These measurements are used to estimate particle density as a function of particle size, which in turn allows estimation of suspended particulate mass (SPM) based on particle size distributions measured with the LISST and DFC. MINSSECT has an in situ water filtration system (McLane Research Laboratories, Inc. Phytoplankton Sampler) for direct measurements of SPM concentration. All instruments are mounted so the centers of the measuring volumes are located 1.2 m above the sea bed. Optical and acoustical properties of the water column are measured by Emmanuel Boss' group from University of Maine, and turbulence in the boundary layer is characterized by John Trowbridge at Woods Hole.

The modeling work is focusing on accurate characterization of the sediment mass in three suspended size classes. Single grains are smaller than 36 μm diameter, and at this point are given a settling velocity of zero. The only way for these particles to clear the boundary layer is to become incorporated into microflocs or macroflocs. Microflocs are aggregates with diameters less than 133 μm and a uniform average settling velocity of 0.1 mm s^{-1}. Macroflocs are large flocs with diameters of greater than 133 μm and a uniform average settling velocity of 1 mm s^{-1}. Mass moves among size classes at rates determined by suspended sediment concentration and turbulent-kinetic-energy dissipation rate, which is a function of boundary shear stress due to waves and currents.

Hill, Law, and Milligan collaborate closely on this project. Together they are providing data and models on the flocculated size distribution of suspended sediment. Law, Milligan, and Hill have responsibility for the MINSSECT. John Newgard (Dal) and Vanessa Page (BIO) provide support in the lab and field. Undergraduate Honours student Alex Hurley completed his thesis on a potential new proxy for suspended particle bulk density and now is an MSc student at Dalhousie.

As mentioned, we collaborate with Emmanuel Boss (UMaine) and John Trowbridge (WHOI) on this project. Boss is responsible for all optical and acoustical characterization of the water column. He has also conducted laboratory manipulations of the particle size distribution in order to explore the effect on optical attenuation. Boss and Hill have worked together on an optical model of marine aggregates. John Trowbridge is responsible for characterizing the stress in the bottom boundary layer during the deployments. We are working with Chris Sherwood from the USGS in Woods Hole on incorporation of our results into the Community Sediment Transport Modeling System (CSTMS). We are working with Dave Bowers at the University of Bangor in Wales to examine the effect of particle composition on optical properties.

WORK COMPLETED

Work in 2011-2012 focused on four areas. First, we gathered and analyzed another data set on particle size at MVCO. Second, with data on particle composition from Dave Bowers at the University of Bangor in Wales, we investigated the quantitative effect of component particle composition on cp:SPM. Third, with 2011 and 2007 field data, we investigated the accuracy of the ratio of c_p to suspended particle volume as a proxy for suspended particle bulk density. Finally, we continued work on developing a simple model of the distribution of mass among size classes in suspension.

RESULTS

Our data set collected in September and October 2011 supports our previous finding that over a range of environmental conditions, the conversion from *SPM* to optical properties is more predictable than the theory that assumes constant-density particles suggests. Particle size only accounts for a factor of 2 in variability, much smaller than the order-of-magnitude hypothesized for decades. The broad conclusion that can be drawn from our work is that particle and optical properties are easier to predict when the stress on the seabed is adequate to resuspend particles. When stresses are too low to resuspend sediment, biology and chemistry determine the concentration, composition, and size of particles in suspension, so biology and chemistry therefore determine optical properties. When stress grows large enough to resuspend particles, however, particle and optical properties are more closely linked to physical forcing, which is fundamentally more predictable. As well, the composition of particles becomes more uniform with increasing stress (Hill et al., 2011).

A corollary of our result that particle size only accounts for a fraction of the observed variability in c_p:*SPM* is that particle composition must cause this ratio to vary. Unknown, however, is how much variability particle composition is likely to produce. If composition varies independently from particle packing geometry within aggregates, then a 2x range in variability is expected. Alternatively, if composition affects particle packing geometry, then a greater than 2x range in variability is possible. We did not collect data on compositional variability in this project, but Dave Bowers at University of Bangor routinely measures mineral and organic fractions in SPM. Analysis of a subset of his data indicate that composition is not correlated with particle packing geometry, so particle composition produces a factor of 2 variability in c_p:*SPM* (Figure 1). This work was presented at Ocean Sciences 2012 is a session co-chaired by Hill, Bowers, Sherwood, and Wayne Slade from Sequoia Scientific. Wayne conducted his PhD research as part of the OASIS project, under the supervision of Emmanuel Boss.

Size and composition together cannot explain observed variability in c_p:*SPM*, leaving particle density as the last particle property to examine. Particle density in suspension typically is estimated first by isolating a suspension in a settling column in which turbulence has been damped and then measuring particle size and settling velocity (e.g., Fennessy et al., 1994; Hill et al., 1998; Hill et al., 2011). With size and settling velocity, it is possible to invert Stokes Law to estimate particle density. This method is effective, but it is invasive, requiring that some of the suspension be isolated in the unnatural environment of a settling column for periods of minutes. It is also labor-intensive, and the custom equipment used to carry out such measurements is found in only a few laboratories around the globe. Thus, the routine measurement of particle density at high temporal resolution has not been possible.

During fall and winter of 2011-2012, Dalhousie Earth Sciences student Alex Hurley undertook a preliminary investigation of a potential new method for estimating particle bulk density in suspension for his undergraduate Honors thesis. Using observations from our 2007 and 2011 OASIS deployments, Alex used a LISST-100x Type B and a digital floc camera (DFC) to estimate sediment mass and volume concentrations in suspension. He estimated sediment mass by making it proportional to the particulate beam attenuation coefficient, and he estimated total sediment volume concentration by merging the size distributions of the LISST and DFC (cf. Hill et al., 2011). With these variables he estimated sediment bulk density in suspension. Alex also used size-settling velocity data from our digital video camera (DVC) to estimate bulk density with the conventional method described above. Alex's comparison of the two methods, dubbed the "LD method" (for LISST and DFC) and the "DVC method" (for the DVC), produced conflicting results between the two years (Figure 2). In 2007 there

was no agreement between the methods. The LD method produced bulk density estimates substantially higher than the DVC method. In 2011, the two methods produced similar density estimates.

The source of the discrepancy in the density comparisons between years is due to systematically lower volume estimates by the DFC in 2007. The reason that the DFC imaged less volume in 2007 is unclear. We have formulated 3 hypotheses:

- The difference in volume estimates between years is real. The DVC method has a lower limit of resolution of ~250 μm, so it is biased toward larger, lower density aggregates. If the suspension in 2007 was dominated by smaller particles, then the DVC method would yield unrealistically low bulk densities.
- The DFC images in 2007 were degraded by absorption by dissolved substances in the water column, causing the image analysis to underestimate particle volume.
- The particles in 2007 had refractive indexes closer to that of water in 2007, making the particles less visible to the image analysis software.

We are in the process of examining these hypotheses with archived data from several sites.

We are using our observations of flocculated size distributions and their response to stress to implement and test models that convert predictions of suspended particulate mass into predictions of the optical properties in bottom boundary layers. Brent Law initiated this work as a final project in a modeling class at Dalhousie in 2011. Chris Sherwood has coded the model in MatLab. This work has been on hold, however, as we continue to clarify the dominant variable(s) responsible for setting c_p:*SPM*.

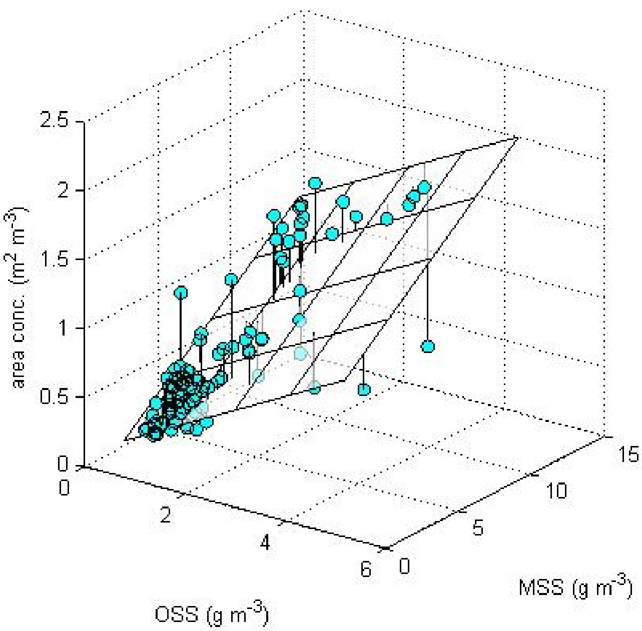

Figure 1. Area concentration in suspension versus organic suspended sediment concentration (OSS) and mineral suspended sediment concentration (MSS). Data from Dave Bowers were collected in a range of coastal environments. The plane shows the best fit linear regression of area concentration on OSS and MSS. If particle composition is uncorrelated with the packing geometry of flocs, then the ratio of the regression coefficient for OSS to the regression coefficient for MSS should be approximately equal to 2. The observed ratio is 2.12. This result suggests that compositional variability accounts only for a 2x range of variability in the c_p:SPM ratio.

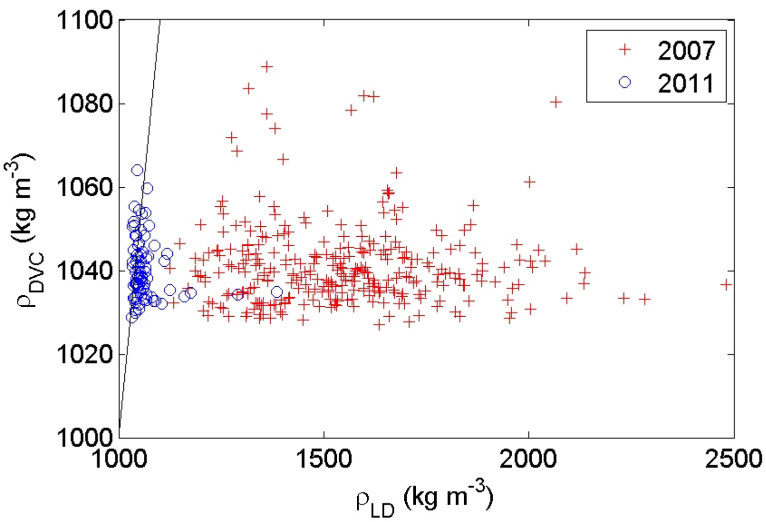

Figure 2. Comparison of bulk density of particles in suspension estimated with two different methods with data from two different OASIS deployments. Estimates from the LD method are plotted on the x axis, and estimates from the DVC method are on the y axis. The 2007 estimates (red crosses) do not follow the 1:1 line shown in black, indicating that the two estimates of bulk density are different. The 2011 estimates (blue circles) do follow the 1:1 line, indicating that the estimates are consistent with one another.

IMPACT/APPLICATIONS

The high-resolution time series of particle, optical, and acoustical properties will enhance understanding of the rates and mechanisms by which the water column clears following storm events. The development of a floc module for CSTMS will enable the implementation of a module that converts sediment to optical properties. The latter advance will provide the sedimentology community with a simple tool to test their model predictions against the most ubiquitous measurement of suspended matter in coastal waters, and it will lead to prediction of in-water optical properties based on predictions of seabed stress.

RELATED PROJECTS

Hill obtained NSERC funding in Canada to purchase of the LISST-100 on the MINSSECT. Hill, Milligan and Law are funded by another Littoral Sciences project to investigate depositional and erosional fluxes on tidal flats. As part of that work, we measured particle size, particle mass, particle settling velocities, optical attenuation, and seabed stress. Law has research into particle transport around aquaculture sites funded by Fisheries and Oceans Canada. This project funded the purchase of another LISST.

Observations made as part of the RIVET DRI are similar to OASIS measurements. They will help to broaden our understanding of the links between particle and optical properties.

Hill and Law are conducting a study similar to the Willapa Bay study on a tidal flat in the macro-tidal Minas Basin of the Bay of Fundy. This work is supported by Nova Scotia through Offshore Environmental and Energy Research (OEER, now OERA). The results from this work augment our understanding of the variables that affect the transformation from optical properties to suspended sediment mass.

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PUBLICATIONS

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